Battle Ground Lake Assessment – Technical Report

Clark County Public Works
Water Resources Section

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Introduction

Battle Ground Lake, located in Southwest Washington State, was treated with an herbicide to control an infestation of Brazilian Elodea during the early summer of 2003. Water quality monitoring coincided with the herbicide treatment to determine the fate and transport of the herbicide within the lake, and to monitor environmental conditions resulting from the treatment. Although extensive sampling for pathogens has been performed by the Clark County Health Department (Carl Addy, personal communication, April 2003) very little data was available for describing the conditions of the lake or for making a diagnostic assessment of lake health and designated use support.

The monitoring plan for the herbicide treatment required monitoring from May to early July for the herbicide and ambient lake parameters (McNickle and others, 2003). Clark County Water Resources (Water Resources) continued monthly monitoring from August to October to supplement the dataset for an assessment of overall lake health. The monitoring provides information about the status of a valuable natural asset for Clark County, and Water Resources uses this information for periodic reporting of the health of county's waterways.

The purpose of this report is to assess the overall health of the lake and to identify potential lake problems that commonly limit recreational and ecological uses.

Parameters for physical, chemical, and biological lake attributes are described and the lake's trophic status is determined (Olem and Flock, 1990). A description of the lake's condition is provided from the preliminary analysis of the data and future monitoring activities are recommended.

Background

Battle Ground Lake State Park has 280 acres of beautiful forest land in the foothills of the Cascade Mountains, 21 miles northeast of Vancouver, Washington. The park is located about two miles northeast of the rapidly growing town of Battle Ground, Washington. The lake itself is of volcanic origin and is considered by some to be a smaller version of Crater Lake in Oregon (Online Highways, http://www.ohwy.com/wa/b/battlwsp.htm). The lake is a very popular recreational resource, offering camping, fishing, hiking, non-motorized boating, swimming and other recreation opportunities. During summer months the lake receives heavy use with the number of users reaching into the hundreds, especially for the swimming beach and fishing dock. The park is largely evergreen forest with four miles of pedestrian trails and five miles of equestrian trails around the lake (Figure 1).

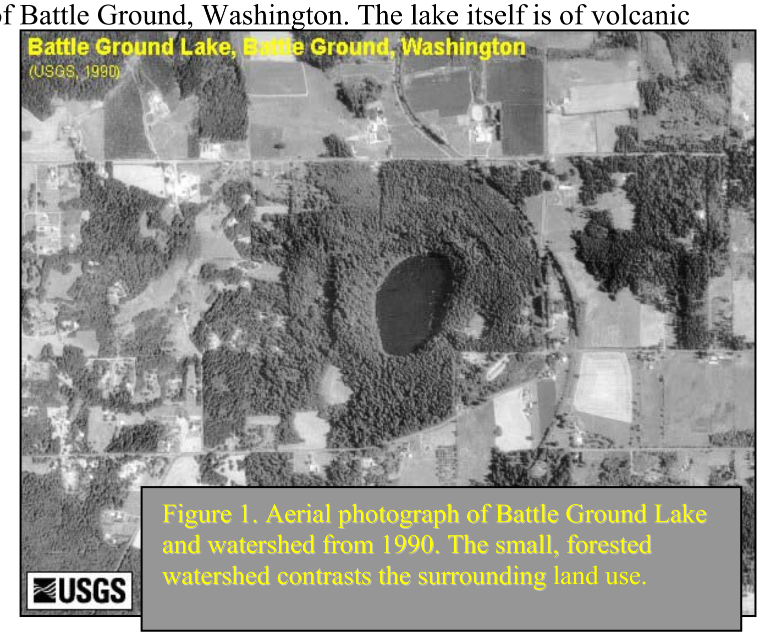


Figure 1. Aerial photograph of Battle Ground Lake and watershed from 1990. The small, forested watershed contrasts the surrounding land use.

The lake's origin is volcanic, and is believed to have been formed as a "Maar" volcano. This type of volcano is the result of hot lava or magma pushing up near the surface of the earth and then coming into contact with underground water. This is thought to have resulted in a large steam explosion, leaving a crater that later formed a lake (Washington State Parks, http://www.parks.wa.gov).

A published study of the lake's sediments showed that the lake has been in existence for at least 20,000 years and has continuously accumulated sediment through most of that time (Barnosky, 1985). Researchers found that in recent history, the last 5,000 years, vegetation was represented by the extensive closed coniferous forests seen today, with hemlock and western red cedar dominating the areas of forest undisturbed by logging.

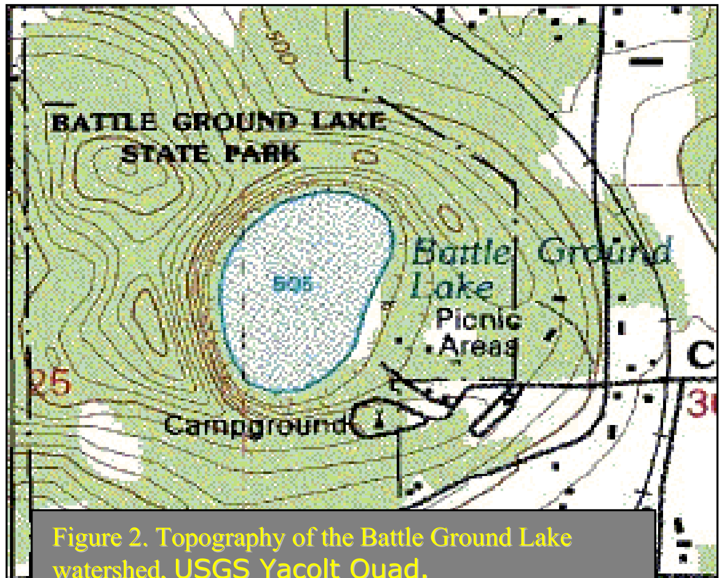


Figure 2. Topography of the Battle Ground Lake watershed, USGS Yacolt Quad.

Battle Ground Lake has a surface area of about 26 acres and a perimeter of about 4,000 feet. Maximum depth is believed to be about 60 feet near the center of the lake, although a few lake users have reported deeper regions believed to be volcanic cracks in the bedrock supporting the lake basin. The lake has a very small watershed, only slightly larger than the surface of the lake itself (Figure 2). As previously mentioned, the primary land use of the watershed is forested park.

With no permanent surface inflow or outflow, precipitation is likely the primary source of water for the lake. The lake's surface elevation is about 500 feet above mean sea level. Given the geologic setting, the topography of the area, and taking into account several surface springs that are reported in the region surrounding the lake, it is likely that Battle Ground Lake is essentially in equilibrium with the regional water table, with the direction of flow varying throughout the season (Rod Swanson, personal communication, January 2004). Climate data from the Western Regional Climate Center for Battle Ground Washington show an average daily maximum and minimum temperature of 62°F and 40°F, respectively. Average annual precipitation and snow deposition is about 52 inches and 6 inches, respectively.

Methods

The ambient monitoring activities followed the general guidelines of the Quality Assurance Project Plan created for the herbicide monitoring effort (McNickle and others, 2003). A single lake station in the center of the lake was selected for the lake assessment sampling. The illustration in Figure 3 shows the location of the four stations used in the herbicide monitoring, and the ambient monitoring station in the center of the lake, Station 4.

Field Procedures

Sample collection and field activities followed standard procedures developed by Water Resources for use in lakes. Water temperature, pH, dissolved oxygen concentration and percent saturation, and conductivity were measured in the field using a calibrated Hydrolab DS4

Revised sampling station locations are approximate; Not to scale

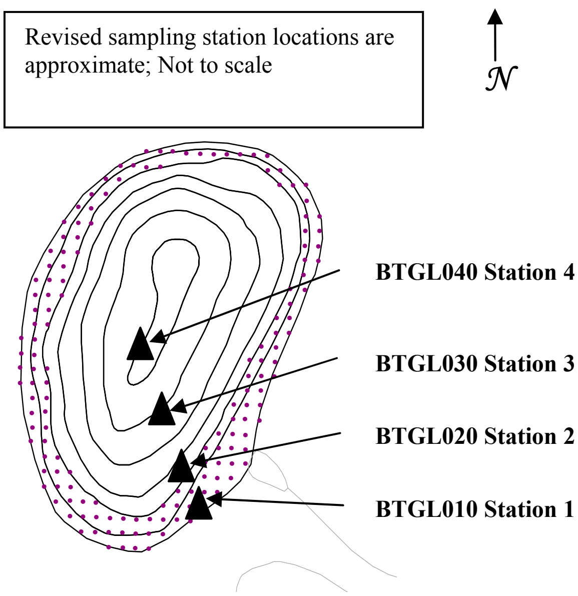


Figure 3. Schematic of sample site locations; BTGL040 Station 4 is the main lake station used in this project; dots indicate the region of Ecology's aquatic plant surveys.

multiprobe. Turbidity was measured in the field with a calibrated Hach 2100P field turbidimeter. Water clarity was measured with a 20-cm Secchi disk and marked rope.

Water samples for total phosphorus were collected from three depths representing the upper, middle, and lower portions of the lake formed by thermal stratification. Samples were collected at depth using an acrylic Van Dorn bottle and then placed in containers recommended by the contract laboratory. A single algal and chlorophyll-a sample was collected from a composite of three depths in the lake representing the surface, Secchi depth, and about twice the Secchi depth. The three depths represent most of the region where enough light is available for photosynthesis.

Lab Procedures
All chemical samples were submitted to North Creek Analytical in Beaverton, Oregon within allowable holding-time limits. Algae samples were preserved and shipped to Aquatic Analysts in White Salmon, Washington for enumeration and identification.

Table 1. Lab procedures for the project.

Analyte	Samples (number & arrival date)	Expected Range of Results	Sample Prep Method	Analytical Method
Total Phosphorus	6, monthly	0-100 µg/L	NA	EPA365.1, Phosphorus, (All Forms), Colorimetric, Automated, Ascorbic Acid
Chlorophyll-a	6, monthly	0-25 µg/L	Filtration	SM10200H3, Chlorophyll-a a and Pheopigment Determination
Algae composition and biomass	2, May and August	NA	Preserved and filtered	SM10200.D.2 Phytoplankton, Permanent Slide Mounts; McNabb, 1960

Results
Thermal Stratification
Thermal stratification is the physical separation of the water column into horizontal layers that typically do not mix. The separation occurs as the sun's rays penetrate the lake's surface and warm the water. Light does not penetrate very deeply in most lakes, so the colder water at the

bottom stays cold. This colder, denser water is confined to the bottom of the lake until stratification is eliminated.

Lake stratification typically occurs during the summer, between mixing periods in the spring and fall when solar radiation is moderated. Stratification has a significant impact on the vertical movement of water and dissolved and suspended material in lakes. During periods of strong stratification, dissolved chemicals, suspended-particulate material, and free floating organisms are confined to a discrete layer.

When monitoring began in late May, Battle Ground Lake was already strongly stratified. The lake remained stratified through the entire monitoring period. Figure 4 shows the water temperature and Relative Thermal Resistance (RTR) per meter of water column throughout the monitoring period. The RTR is basically the difference in the density of water for each meter of water column, normalized to the density difference of water between 4°C and 5°C. Very high RTR values are observed where there are large differences in water temperatures, per meter vertically.

The depth where the RTR is the highest usually marks the layer of stratification that acts as a barrier to the movement of water and materials in lakes. The lake was very strongly stratified in July and August. The thermocline, or depth at which temperature and density differences are the greatest, migrated deeper in the water column as the season progressed, increasing the thickness of the mixed layer at the water's surface.

Water Temperature

The water temperature of the upper layer of lakes, or epilimnion, regulates metabolic processes for most aquatic organisms including algae, zooplankton, macroinvertebrates, and fish. Certain algal species grow well in warmer water and certain fish, trout and other salmonids for example, require cooler water to be productive. The general water quality criteria for lakes in Washington State require "all lakes and all feeder streams to lakes (reservoirs with a mean detention time greater than fifteen days are to be treated as a lake for use designation) to be protected for the designated uses of salmon and trout spawning, core rearing, and migration; and extraordinary primary contact recreation" (Washington Administrative Code 173-201A-600).

The maximum water temperature for the upper layer of the lake was about 25°C in July, and ranged from about 15°C in October to 18°C in May. The warm surface temperature would have facilitated the growth of green and blue-green algae throughout most of the summer. Also, the higher temperatures may limit salmonid production. Colder water was available with depth, as water temperatures remained below 15°C at depths greater than 6-7 meters all summer. However, as described in the following section, the cold water refugia may be limited by oxygen availability.

Dissolved Oxygen

Dissolved oxygen in the lake decreases dramatically with depth. There was often a slight increase in concentration near the thermocline, where algal cells concentrate and produce oxygen through photosynthesis (Figure 5). However, there is essentially no oxygen in the lower layers of the lake deeper than 6-7 meters throughout most of the summer. Figure 6 shows the median and inter quartile range of oxygen in the upper and lower layers of the lake. The decomposition of settled organic matter, such as algae and aquatic plant material, by microorganisms consumes oxygen in the lower layers. The resistance to vertical mixing does not allow fresh oxygen from the atmosphere to distribute through the water column and the lower layer eventually becomes

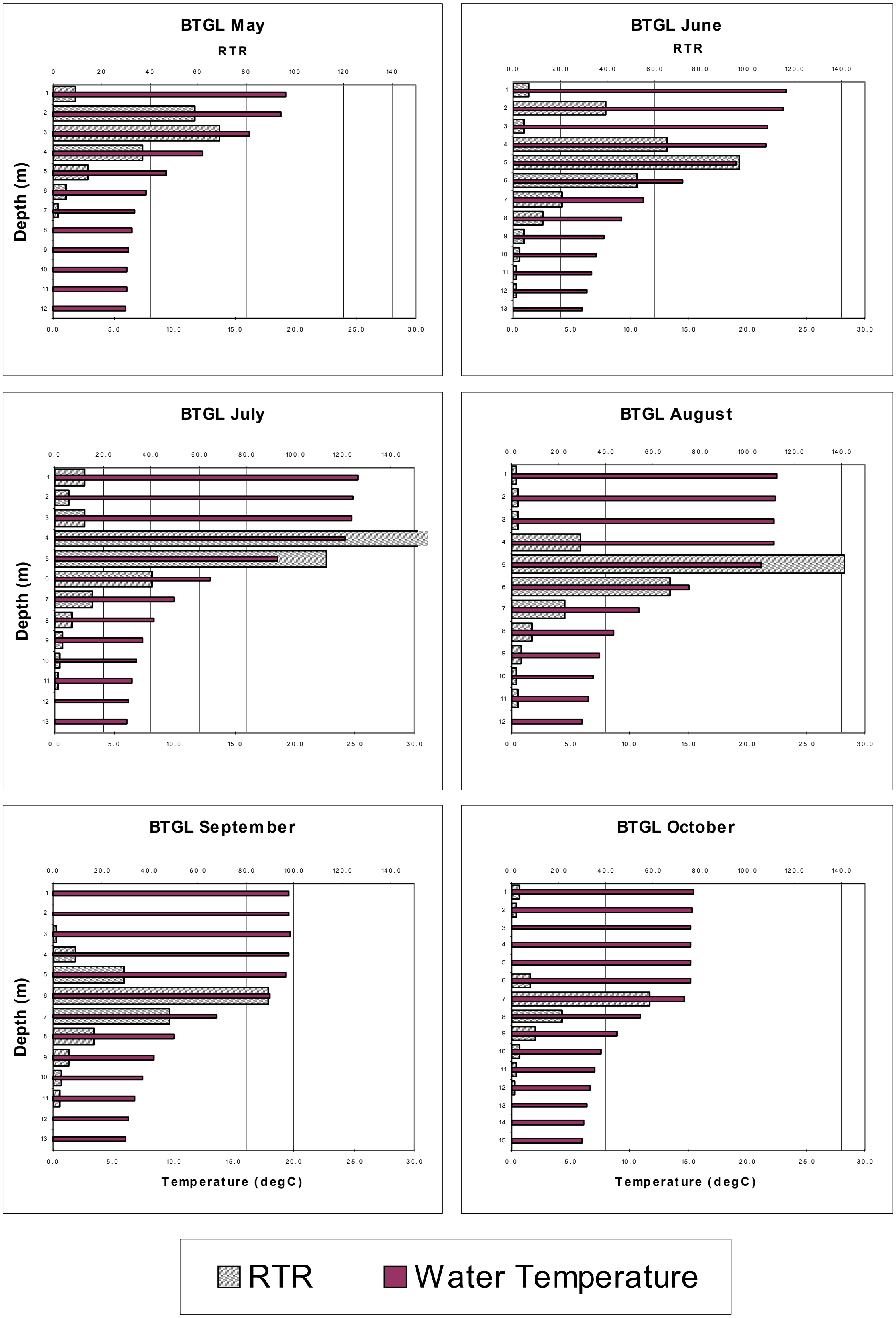


Figure 4. Water Temperature and Relative Thermal Resistance (RTR) values showing thermal stratification in Battle Ground Lake, May-October, 2003.

anoxic. Only the vertical mixing of the water column will re-distribute oxygen to the lower lake layer.

The limited availability of oxygen below about five meters restricts habitat for fish that would be seeking cooler waters during the summer. The fish would be forced to occupy warmer surface layers where more oxygen is available.

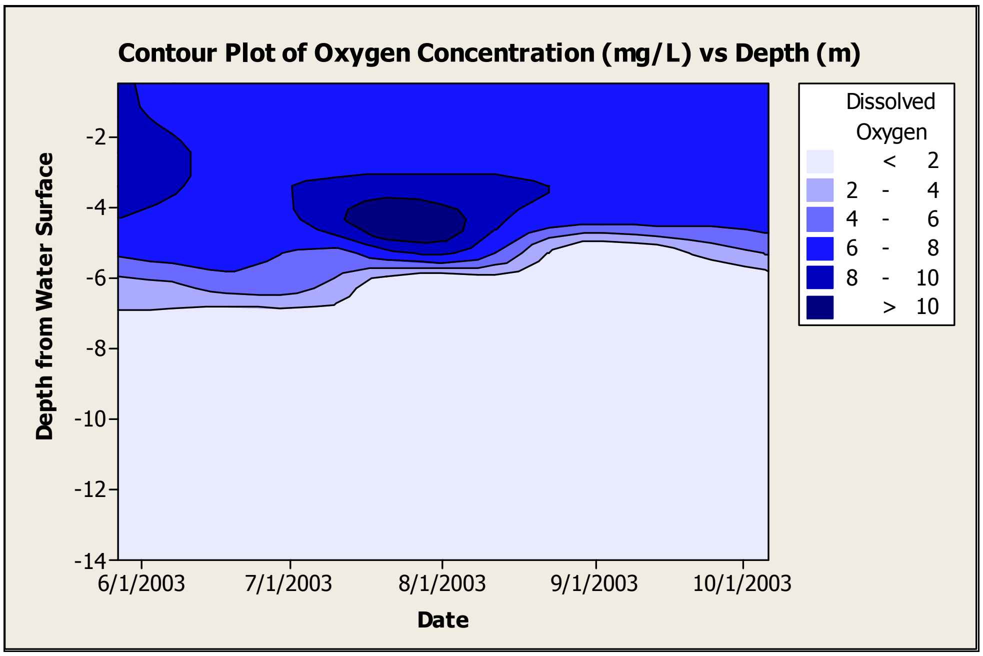
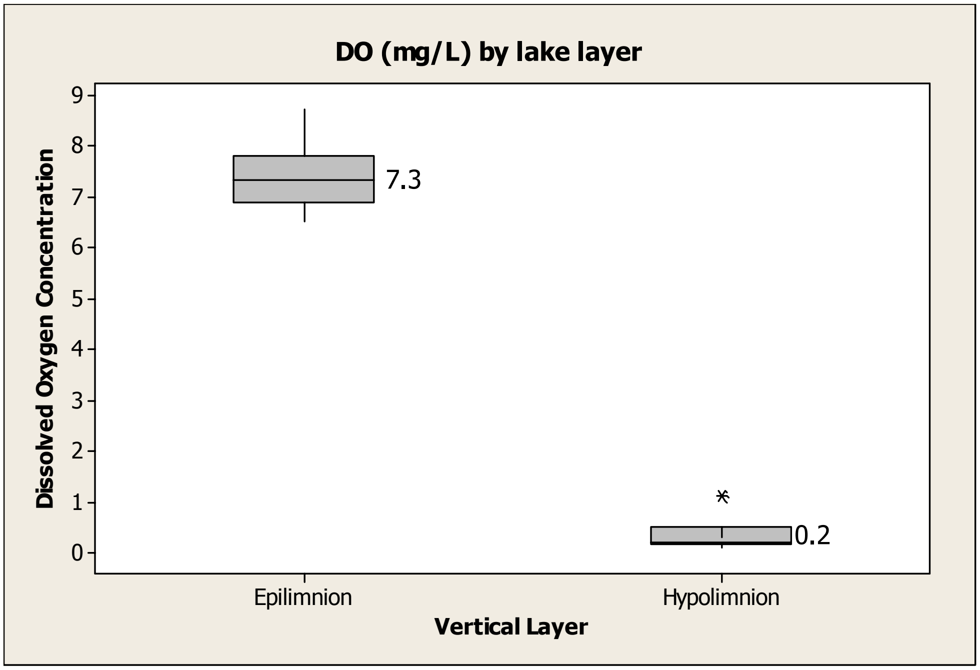


Figure 5. Dissolved oxygen distribution with depth in Battle Ground Lake, May-October 2003; Note the slight increase in oxygen at 4-5 meters during August where algae concentrate at the thermocline.

pH

The median and inter quartile range of pH values observed in the upper and lower layers of the lake is shown in Figure 6. The lake was slightly acidic and the pH of the hypolimnion was significantly lower than the upper layer, most likely an artifact of the strong thermal stratification and lack of vertical mixing. The lower pH values near the bottom of the lake most likely influence the interaction of chemicals such as phosphorus and metals in the lake’s sediments.



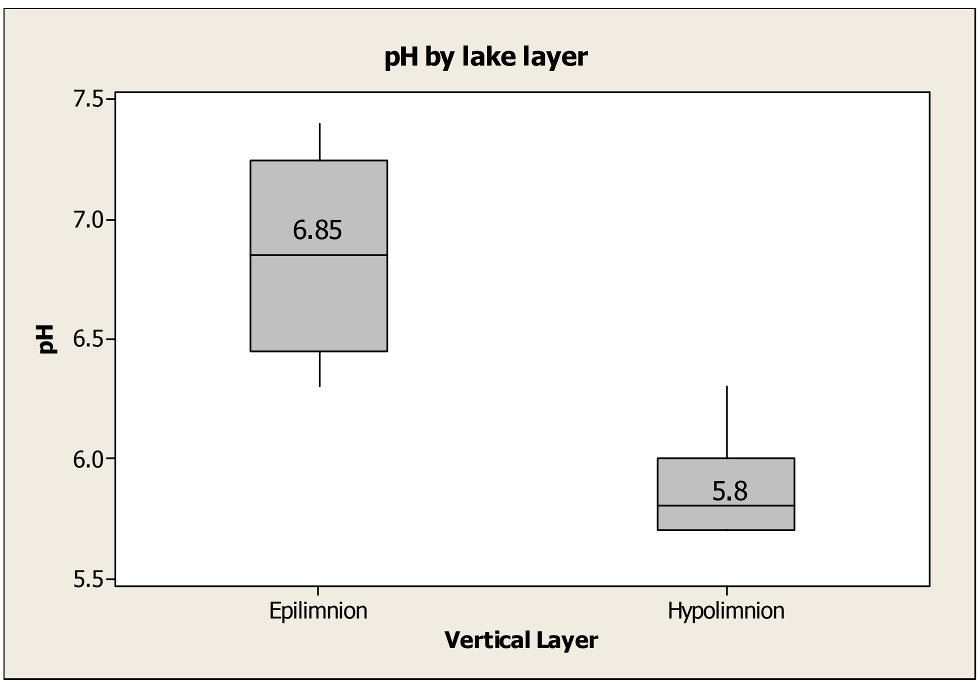


Figure 6. Battle Ground Lake median (values shown) and inter-quartile range of dissolved oxygen concentration and pH, May-October, 2003.

Conductivity

The conductivity of the lake, or the measure of the level of dissolved substances, is very low and stable to about 10 meters, typically ranging from 16-20 µS/cm. This would be expected from a lake with the primary source of water being nearly-pure rainwater. However, at depths greater than 10 meters, the conductivity increases sharply, up to nearly 200 µS/cm near the bottom. Nutrient data also supports this observation. The sharp increase is more evidence of very strong thermal stratification in the lake, indicative of infrequent mixing and accumulation of material near the sediments.

Water Transparency

Transparency represents light penetration in a lake and is measured with a standard Secchi disk, a 20-cm white and black disk lowered into the water to the point it is no longer visible. Secchi values through the summer are shown in Figure 7. Light penetration is relatively good in Battle Ground Lake. The shallowest Secchi depth was about 2 meters in July. However, this may have been related to the herbicide application and subsequent die-off of aquatic plants in late June. Nutrients that were released by the decaying plants may have stimulated algal growth, or the competition with plants for available nutrients may have been reduced or eliminated by the herbicide treatment. As will be discussed later, algal biomass as indicated by chlorophyll-a level was high in July, which could reduce light penetration and the visibility of the Secchi disk.

In a typical year, without an herbicide application, the light penetration in the lake may be good throughout the summer. Algal density most likely affects the water clarity and Secchi depth would fluctuate with algal blooms. Secchi values of 5-7 meters during the summer indicate good lake quality. The section of this report discussing trophic state will interpret Secchi depths in relation to algal growth.

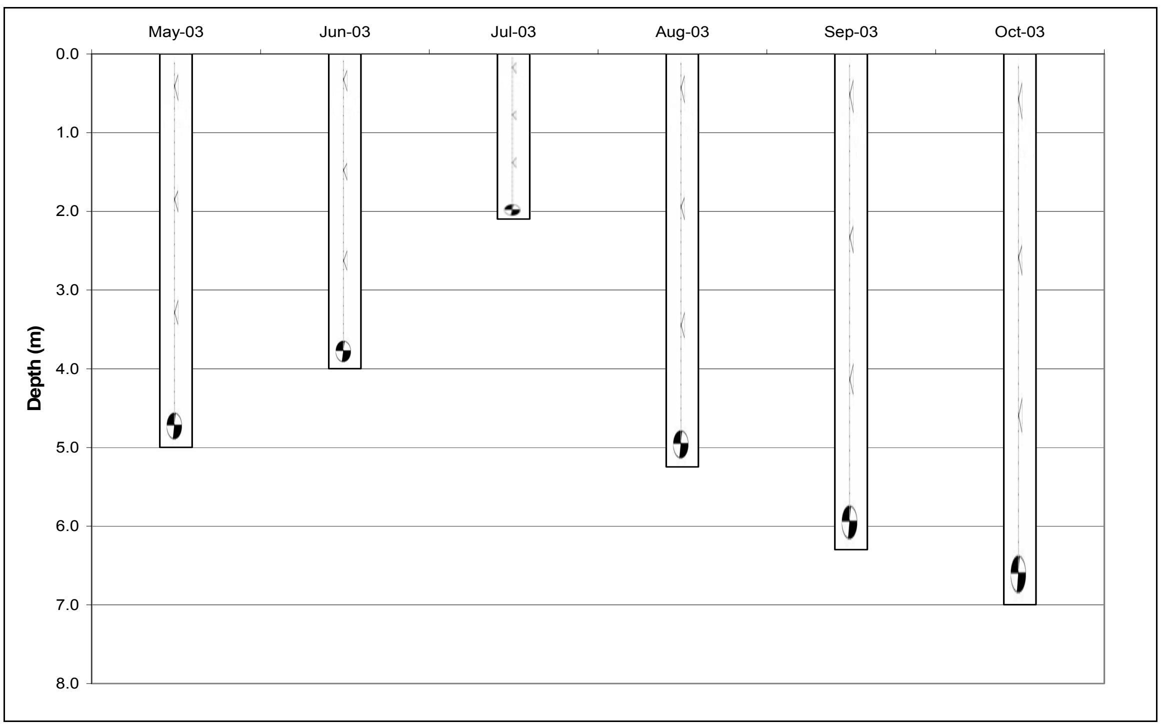


Figure 7. Secchi depth observed in Battle Ground Lake, May to October, 2003.

Total Phosphorus

Algal growth in lakes is often limited by nutrient availability, primarily inorganic forms of phosphorus and nitrogen. Scientists have made observations regarding the levels of total phosphorus (TP) that have been observed with nuisance algal blooms and other lake problems associated with advanced eutrophication. Furthermore, Washington State uses nutrient criteria to assess lakes and determine whether action needs to be taken to reduce nutrient loading (Washington Administrative Code 173-201A-230).

Washington State TP criteria are assigned by ecoregion but have not been determined for the Willamette Valley Foothills Ecoregion, where Battle Ground Lake is located. An approximate "action level" may be used from the near-by Coast Range, Puget Lowlands, and Northern Rockies Ecoregions set at 20 µg/L (Washington Administrative Code 173-201A-230).

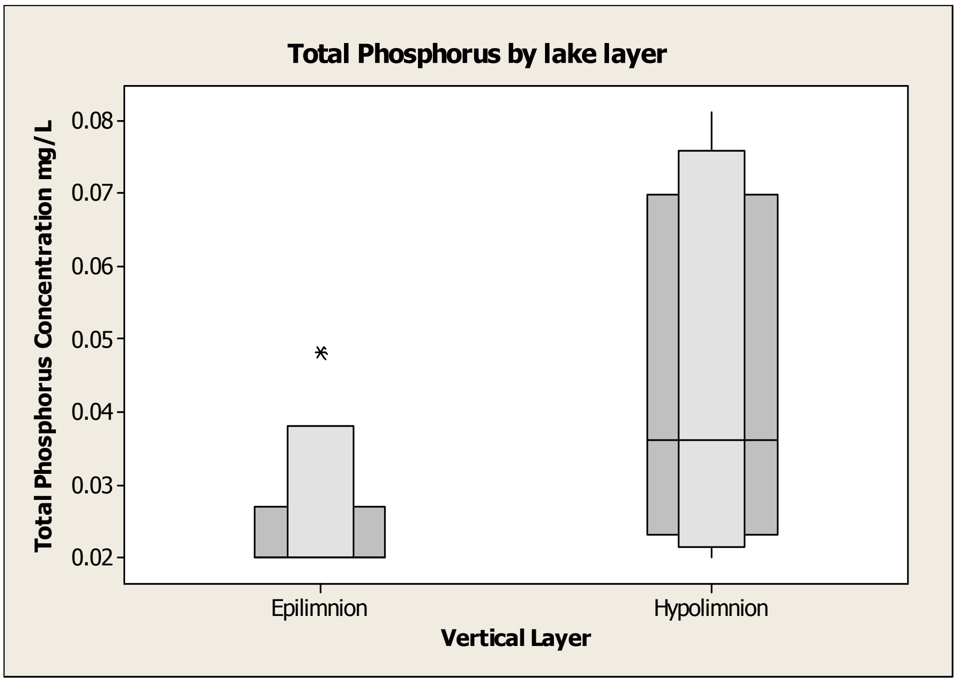


Figure 8. Median and inter-quartile range of total phosphorus concentration values during the summer months in Battle Ground Lake. The lighter gray boxes show the 90% confidence interval of the data. Reporting limits for TP analysis were 20µg/L, the median value for the epilimnion group.

Five out of six samples had epilimnetic TP concentrations below 20 µg/L during the summer of 2003. Total phosphorus concentrations were significantly higher in the bottom layer of the lake relative to the surface layer (Figure 8). Most of the data from the surface layer and all samples collected from the middle layer were below the laboratory's reporting limit of 20 µg/L. The average TP concentration in the bottom layer was about 45 µg/L and ranged as high as 80 µg/L.

The section of this report discussing trophic state will interpret total phosphorus concentration in relation to algal growth.

Chlorophyll-a

Chlorophyll-a is a pigment used to capture energy from the sun for photosynthesis. In various forms, it is present in all major divisions of algae. Scientists have found that the level of chlorophyll-a in an algal cell is typically 1-2% of its overall mass, and thus can be used as a rough indicator of biomass in a lake (Wetzel, 1983). Phytoplankton levels and hence chlorophyll-a levels are highly variable throughout the summer. The sampling in Battle Ground Lake was not intended to capture the variability of chlorophyll-a, but to estimate an overall average during the summer months.

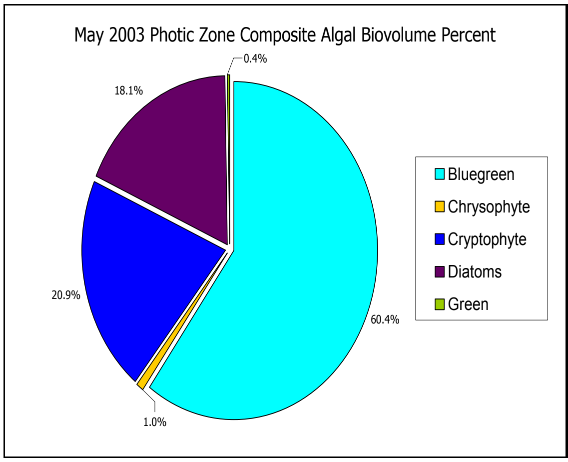
Grab samples were composited from evenly spaced depths through the photic zone of the lake. The average chlorophyll-a concentration in the photic zone was about 9.2 µg/L and ranged from below 1 µg/L to nearly 30 µg/L. This range gives an estimate of average algal biomass of about 600 µg/L, ranging from low to over 2 mg/L.

The section of this report discussing trophic state will interpret chlorophyll-a in relation to algal growth.

Algae

Algae are very important organisms in the food structure of lakes. Free-floating and attached forms often make up the entire platform of primary production in an aquatic environment, and thus account for most of the energy captured from the sun. Battle Ground Lake has dense submerged aquatic plant beds along the shoreline or littoral area, but most of the habitat is open water and free-floating forms of algae are important factors of production and food availability. Additionally, the type and density of algae present affects lake chemistry and water clarity.

Photic zone composite samples were collected in May and August. Algae were enumerated and identified, and overall biovolume, or the total volume of all algal cells, of the sample was calculated.



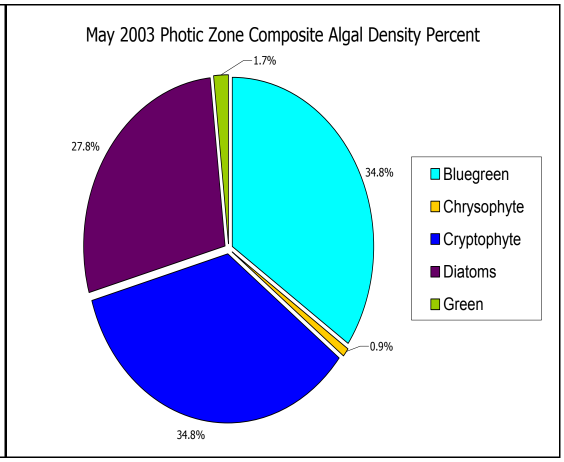


Figure 9. Algal biovolume and density of major algal groups for the May 2003 sample.

Figure 9 above shows the make-up of the algal community during the spring of 2003 in Battle Ground Lake. Biovolume, as described above, is an indicator of the overall amount, which helps account for the difference in size among many algae types. Density is the number of algal units that were counted per a given unit of water volume, typically per milliliter. The blue-green algae *Aphanizomenon flos-aquae* dominated the biovolume of the sample and accounted for much of the overall density. The Cryptophytes *Rhodamonas minuta and Cryptomonas erosa* are small, flagellated algae that made up about a third of the density and slightly less of the biovolume. Also present in high numbers was the Diatom *Synedra radians*, which is a common algae in Northwest lakes during the spring.

The dominance of the spring sample by blue-green algae is interesting. Typically the dominance by blue-greens takes place in mid to late-summer, where water temperature, stratification, and nutrient conditions favor heavy growth by this group. This monitoring effort was not detailed enough to explain the presence of *Aphanizomenon* during the spring; however, stratification and higher phosphorus concentration may lead to favorable conditions earlier in the year.

Figure 10 below shows the make-up of the algal community during August of 2003. Algal biovolume and density were dominated by colonial forms of Green algae *Gloeocystis, Oocystis* and *Spaerocystis. Aphanizomenon flos-aquae* and *Cryptomonas erosa* were also present in fewer numbers than noted in the spring. The Chrysophyte *Chromulina sp.* was present in relatively high numbers during the summer, but accounted for only a small percentage of the overall biovolume.

The overall biovolume of the spring sample was nearly twice as high as during the late summer, in fact the biovolume of *Aphanizomenon flos-aquae* alone in May was higher than the total biovolume observed during August. This reduction in biovolume corresponds to lower levels of total phosphorus and increased water clarity during the late-summer months.

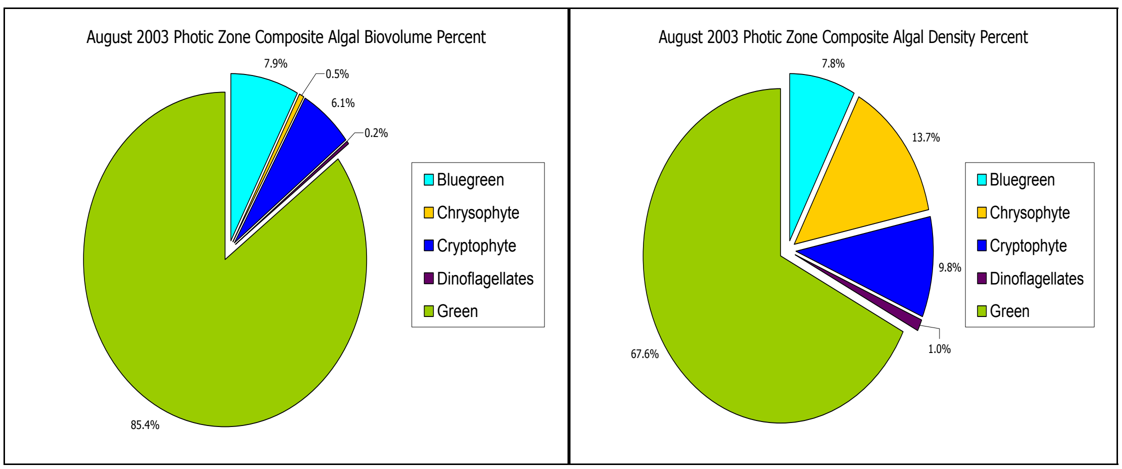


Figure 10. Algal biovolume and density of major algal groups for the August 2003 sample.

Trophic State Index

A Trophic State Index (TSI) is basically used to describe the level of production of a lake, or the amount of algal matter produced by photosynthesis in a lake (Carlson, 1981, Wetzel, 1983). The amount of algal matter has proven to be a reliable measure of the problems that typically plague lakes. An index generally uses a numbered scale to compare variables with one another, or with a reference number. So the TSI provides a measurement of algal biomass along a scale referenced to the conditions observed in lakes. A biomass-related trophic state definition places the emphasis of the lake classification on the problem (e.g. too much algae or too many aquatic plants which, in turn, interfere with lake uses) rather than on any potential cause (e.g. too many nutrients) (Carlson and Simpson, 1996).

The terms used to characterize lakes by an amount of algae and plant production are oligotrophic, mesotrophic, and eutorophic, or low, medium, and high algal production, respectively. The TSI interprets algal biomass, or measured indicators of algal biomass, and expresses the result on a numbered scale that is easy to understand, approximately from zero to one hundred. A single measurement of TSI does not imply whether a lake's health is deteriorating, nor does it imply where a lake *should be* in terms of the current health. The term eutrophication refers to the movement of a lake along a continuum, in a direction from oligotrophy towards eutrophy, or from low to high algal production. Sometimes this movement is considered *accelerated* due to events in the lake or watershed.

The following equations, taken from Carlson and Simpson, 1996, were used to calculate the TSI from chlorophyll-a , Secchi depth, and total phosphorus data. The equation calculating TSI from algal biovolume was provided by the consultant performing the algal counts (Jim Sweet, personal communication, December 2003):

- TSI(SD) = 60 - 14.41 ln(SD), where SD is Secchi depth in meters;
- TSI(CHL) = 9.81 ln(CHL) + 30.6, where CHL is chlorophyll-a in μg/L;
- TSI(TP) = 14.42 ln(TP) + 4.15, where TP is total phosphorus in μg/L;
- TSI (BV) = (Log-base 2 (B+1))*5, where B is the phytoplankton biovolume in cubic micrometers per milliliter, divided by 1000.

Figure 11 shows the median and range of TSI values calculated for the specific parameters during the summer of 2003.Average TSI values derived from the algal indicators were about 45-50, indicating a lake in the mesotrophic category, or a medium level of algal production. Lakes in this range are typically clear with established aquatic plant beds and have a moderate level of nutrients. Algal biovolume and chlorophyll-a average TSI values generally were in agreement, although some variability between the index values can be expected (Figure 12). In some situations, the variability among the parameters is not random and factors interfering with the relationship can be identified. The deviations of the total phosphorus or the Secchi depth index from the chlorophyll-a index, for example, can be used to identify errors in collection or analysis, or real deviations from the "standard" expected values (Carlson, 1981).

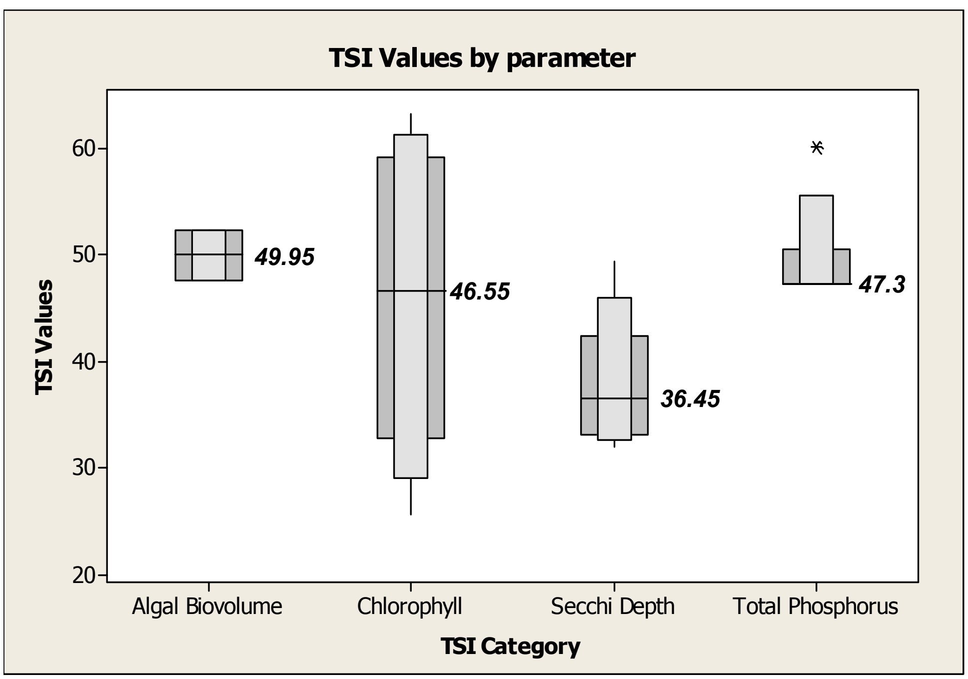


Figure 11. Median and inter-quartile range of TSI values during the summer months in Battle Ground Lake. The lighter gray boxes show the 90% confidence interval of the

data. Note that the TP values were censored according to the lab's reporting limits, and thus there is no data below the median of about 47.

Although TSI values derived from TP were in good agreement with the algal indicators (Figure 11), most of the data was censored based on the lab's reporting limit of 20 µg/L, and thus TSI cannot be calculated below the mid-mesotrophic range. The TSI based on Secchi depth was lower than the biovolume and chlorophyll-a estimates. Scientists have found that instances where Secchi TSI is lower than algal TSI are possible when large algal cells dominate algal populations, which was the case in both samples collected in the spring and fall (See Figures 8 and 9).

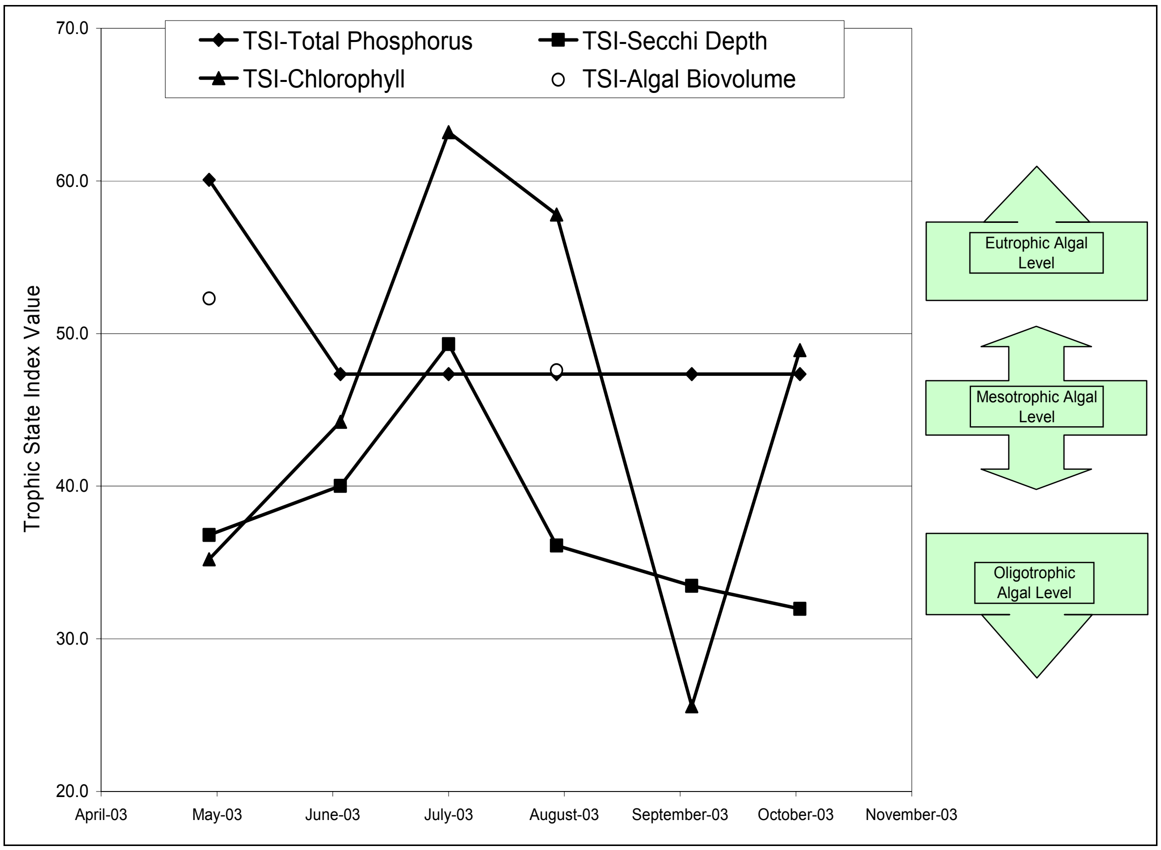


Figure 12. TSI plot of the individual predictors TP, Secchi depth, chlorophyll-a, and algal biovolume in Battle Ground Lake, May to October, 2003.

Summary

Battle Ground Lake is a valuable recreational resource for residents in Clark County. The lake is also unique in its volcanic origin and setting in the landscape, particularly with a small watershed that is only slightly larger than the lake's surface area. There are no surface inlets or outlets to the lake. The only sources of water to the lake are groundwater seepage, precipitation and direct overland runoff from the land and trails surrounding the lake.

The most striking characteristic of the lake is the strength of thermal stratification, or separation of the lake into vertical layers. This separation was present early in the season, at least by May, and persists throughout the summer and early fall. The separation of layers has significant implications for the transport of materials from the lake's surface to sediments, and vice versa.

Dissolved oxygen concentration in the lower layer of the lake is significantly impacted by the stratification. There is essentially no oxygen below a depth of about 5 meters, where the process of decomposing material consumes the oxygen in the water. Atmospheric oxygen dissolves into the water at the lake's surface, but is not transported to the deeper regions. The lack of oxygen in much of the lake's volume, coupled with the high temperatures in the upper layer, significantly reduces the habitat available for certain aquatic organisms. The lack of oxygen near the lake bottom is often a characteristic of more productive systems and can be a symptom of eutrophication. However, without a history of the lake's water quality it is difficult to state whether this is a recent problem or a feature influenced by the lake's unique hydrology. Further study would help define the water movements within the lake throughout the year and help determine the occurrence and extent of oxygen depletion.

Total phosphorus concentration in the surface layer is often used as an indicator of lake health. TP was typically low, below 20 μg/L, in the surface layer throughout the summer and not necessarily considered to be a primary cause of algal blooms. Higher levels of TP were observed near the sediments, most likely a result of settled material accumulating near the bottom. Further study would be necessary to determine if the sediments are releasing phosphorus and can be considered a source to the upper water column.

The trophic status of the lake is in the upper mesotrophic range as indicated by algal biovolume and chlorophyll-a levels. This suggests a medium level of production along the scale of trophic status. It cannot be concluded at this point whether trophic status is rapidly changing or degrading. The dominance of the algae population by blue-green algae in the spring is noteworthy because of the potential formation of nuisance algal blooms. During the summer the overall amount of algae was lower than the spring and was dominated by green algae, generally considered to be more indicative of a less productive system. High levels of blue-green algae can diminish the recreational enjoyment of lakes during the summer months and should be monitored in the future.

The primary uses of Battle Ground Lake do not appear to be limited by water quality based on the results of this project. Ongoing monitoring would help describe the variability in the lake's characteristics and more importantly, track changes in the health of this valuable resource. At a minimum, routinely measuring the Secchi Disk depth and occasionally taking samples for analysis of algal composition would provide information valuable to lake managers.

Acknowledgments

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For further information, comments, or concerns, please contact Ron Wierenga at 360-397-6118 x4264 or at ron.wierenga@clark.wa.gov.

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